MÖSSBAUER AND ELECTRON MICROPROBE STUDIES OF DENSITY SEPARATES OF MARTIAN NAKHLITE MIL03346: IMPLICATIONS FOR INTERPRETATION OF MÖSSBAUER SPECTRA ACQUIRED BY THE MARS EXPLORATION ROVERS.

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Introduction: Martian meteorite MIL03346 is described as an augite-rich cumulate rock with ~80%, ~3%, and ~21% modal phase proportions of augite (CPX), olivine and glassy mesostasis, respectively, and is classified as a nakhlite [1]. The Mossbauer spectrum for whole rock (WR) MIL 03346 is unusual for Martian meteorites in that it has a distinct magnetite subspectrum (~7% subspectral area) [2]. The meteorite also has products of pre-terrestrial aqueous alteration ("iddingsite") that is associated primarily with the basaltic glass and olivine.

The Mossbauer spectrometers on the Mars Exploration Rovers have measured the Fe oxidation state and the Fe mineralogical composition of rocks and soils on the planet's surface since their landing in Gusev Crater and Meridiani Planum in January, 2004 [3,4]. The MIL 03346 meteorite provides an opportunity to "ground truth" or refine Fe phase identifications. This is particularly the case for the so-called "nanophase ferric oxide" (npOx) component. NpOx is a generic name for a ferric rich product of oxidative alteration. On Earth, where we can take samples apart and study individual phases, examples of npOx include ferrihydrite, schwertmannite, akagaaneite, and superparamagnetic (small particle) goethite and hematite. It is also possible for ferric iron to be associated to some unknown extent with igneous phases like pyroxene.

We report here an electron microprobe (EMPA) and Mössbauer (MB) study of density separates of MIL 03346. The same separates were used for isotopic studies by [5]. Experimental techniques are described by [6,7].

Samples: [5] prepared four density separates: <3.32 g/cm^3 as the "glass" sample; 3.32-3.45 g/cm^3 as the augite "core" sample; 3.45-3.7 g/cm^3 as the augite "rim" sample; and >3.7 g/cm^3 as the olivine sample. The olivine sample was completely consumed by [5], so we analyzed only the first three samples. The augite core sample was a reasonably monomineralic sample, but the glass and rim samples were complex assemblages including glass plus magnetite, olivine, and augite core and rim material. The glass separate, however, did have significantly more glass.

EMPA results: Table 1 gives the average major element composition for the augite core and rim, mesostasis fayalite and Ti-magnetite, and glass. The composition for a Fe-rich vein (putative npOx) in the

glass is given in the last column. The vein was smaller than the beam diameter, so the analysis represents a mixture of vein material and host glass. Thus the Fe concentration is a probable lower limit for vein material. Note that the glass has a very low FeO content (~3.4%), especially in comparison to the npOx (>19.6%). The augite core and rim compositions are in good agreement with those published by [1].

Mossbauer results: MB spectra for the WR and the three density separates are shown in Fig. 1. Subspectra for two of the least squares fits are shown in Fig. 2, where the Fe-bearing phases are identified. The derived Mossbauer parameters are given in Table 2.
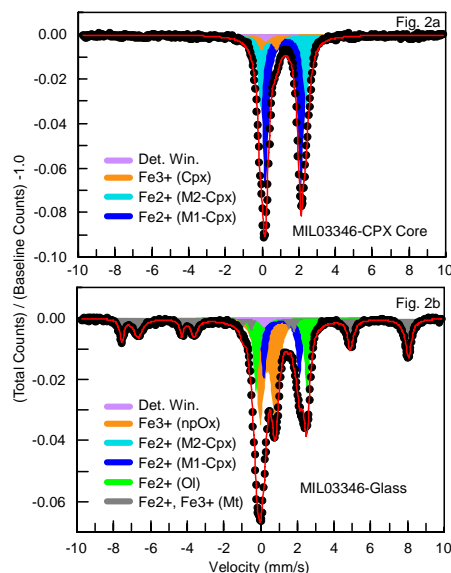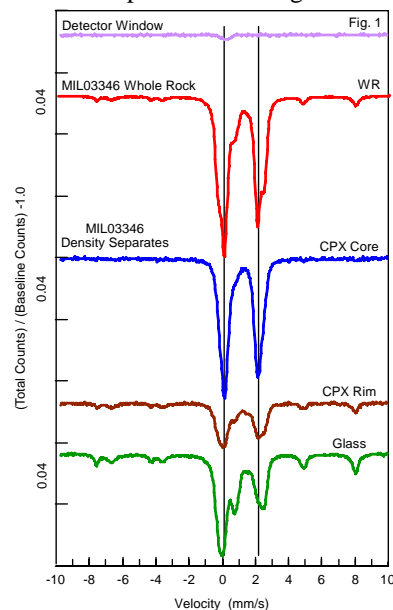

Fig. 1

Fig. 2a

Fig. 2b

Table 1. Major element composition of Whole Rock MIL03346, clinopyroxene core and rim, Ti-magnetite, glass, and nanophase ferric oxide

(%)	WR[a]	CPX Core	CPX Rim	Fayalite	Ti-Mt	Glass	npOx
SiO_2	49.2	51.9(0.4)	48.4(1.7)	29.4(1)	0.8(0.4)	64.4(2.7)	55.5
TiO_2	0.07	0.2(0)	0.5(0.1)	0.1(0)	16.8(1.3)	0.1(0)	0.3
Al_2O_3	3.59	0.9(0)	2.3(1.2)	0.4(0.3)	3.2(0.7)	19.3(1.4)	13.1
Cr_2O_3	0.19	0.3(0)	0(0)	0(0)	0(0)	0(0)	0.0
FeO^b	19.23	13.6(0.4)	22.5(4.3)	59.6(3.3)	71.5(2.9)	3.4(1.7)	19.6
MnO	0.45	0.3(0)	0.6(0)	1.7(0.1)	0.5(0)	0(0)	0.2
MgO	9.33	12.8(0.3)	7.3(2.4)	2.2(0.3)	0.1(0)	0(0)	1.7
CaO	15	19.1(0.2)	16.7(1.2)	0.2(0.1)	0.1(0)	3.7(0.6)	1.7
Na_2O	1.01	0.2(0)	0.2(0)	0(0)	0(0)	5.8(0.7)	0.9
K_2O	0.29	--	--	--	--	--	--
P_2O_5	0.22	0(0)	0(0)	0.3(0.2)	0(0.1)	0.1(0.1)	0.1
TOTAL	98.34	99.8(0.4)	98.9(1.3)	94.1(3.4)	93.4(3.5)	97.3(1.4)	93.2

[a]From Treiman *et al.* 2005.
[b]Total iron as FeO.

Two important results for the interpretation of MER Mossbauer spectra are evident in Table 2. First, there is only minor Fe^{3+} potentially associated with the pyroxene (at most 7% of total pyroxene Fe; Column A, Table 2). This is a factor of >3 less potential Fe^{3+} than reported by [6], and the result is consistent with MER data. And second, npOx is primarily associated with the glass separate, and presumably corresponds to the Fe-rich material (lateration product) in the veins of the glass and associated with the fayalite (iddingsite). The low total Fe concentration of the glass (~3.4% as FeO; Table 1) and the observation that low-Fe3+ augite is crystallizing from it suggest that there is not a significant contribution to npOx from Fe^{3+} in glass. It is difficult to prove this, however, because we do not know the relative volume proportion of glass compared to the altered material in veins and iddingsite derived from olivine (fayalite).

References: [1] Treiman A. H. (2005) Chemie der Erde 65, 203. [2] Morris R.V. et al. (2006), LPSC37, #1594. [3] Morris R. V. et al. (2006) JGR, 111, E02S13, doi:10.1029/2005JE002584. [4] Morris R. V. et al. (2006) JGR, 111, E12S15, doi:10.1029/2006JE002791. [5] Shih C.-Y. (2006), LPSC37, #1701. [6] Dyar, M.D. et al. (2005) JGR, 110, E09005, doi:10.1029/2005JE002426.

Table 2. MB parameters (295 K) for MIL 03346.

Site	Phase	δ (mm/s)	ΔE_Q (mm/s)	B_{hf} (T)	A (%)
CPX Core Separate					
Oct-Fe^{2+}	Px	1.16	1.93	---	63
Oct-Fe^{2+}	Px	1.17	2.48	---	30
Oct-Fe^{3+}	npOx?	[0.38]	[0.82]	---	7
CPX Rim Separate					
Oct-Fe^{2+}	Px	[1.16]	[1.93]	---	32
Oct-Fe^{2+}	Px	[1.17]	[2.48]	---	19
Oct-Fe^{2+}	Fa	1.15	2.89	---	12
Oct-Fe^{3+}	npOx	[0.38]	[0.82]	---	13
Oct-$Fe^{2.5+}$	Mt	[0.67]	[0.00]	[45.5]	17
Tet-Fe^{3+}	Mt	[0.27]	[-0.01]	[48.6]	7
Glass Separate					
Oct-Fe^{2+}	Px	[1.16]	[1.93]	---	16
Oct-Fe^{2+}	Px	[1.17]	[2.48]	---	9
Oct-Fe^{2+}	Fa	1.15	2.79	---	18
Oct-Fe^{3+}	npOx	0.39	0.81	---	32
Oct-$Fe^{2.5+}$	Mt	0.67	0.00	45.5	14
Tet-Fe^{3+}	Mt	0.27	-0.01	48.6	7

Notes: Parameters in square brackets were constrained during the fitting procedure. Subspectral areas are not f-factor corrected. δ and ΔE_Q uncertainties are ±0.02 mm/s; B_{hf} uncertainty is ±0.8 T; A uncertainty ±2% absolute.